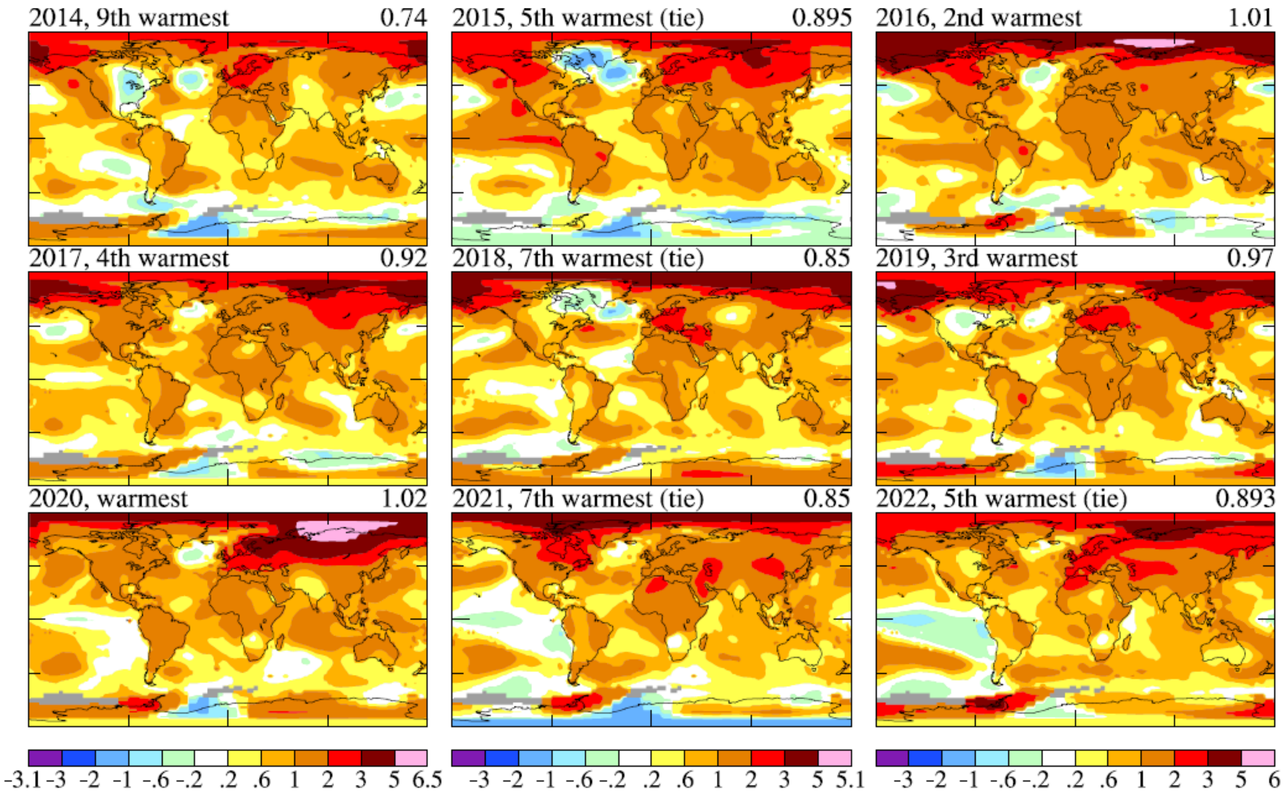

Fig. 1. Surface temperature relative to 1951-1980 average for the past nine years.

Global Temperature in 2022

12 January 2023

James Hansen, Makiko Sato and Reto Ruedy

Global surface temperature in 2022 was +1.16°C (2.1°F) in the GISS (Goddard Institute for Space Studies) analysis[1,2,3] relative to 1880-1920, tied for 5th warmest year in the instrumental record. The current La Nina cool phase of the El Nino/La Nina cycle – which dominates year-to-year global temperature fluctuation – had maximum annual cooling effect in 2022 (Fig. 1). Nevertheless, 2022 was ~0.04°C warmer than 2021, likely because of the unprecedented planetary energy imbalance (more energy coming in than going out). The already long La Nina is unlikely to continue, tropical neutral conditions are expected by Northern Hemisphere spring, with continued warming as the year progresses. Thus, 2023 should be notably warmer than 2022 and global temperature in 2024 is likely to reach +1.4-1.5°C, as our first Faustian payment of approximately +0.15°C is due.

1	2020	1.29
2	2016	1.28
3	2019	1.24
4	2017	1.19
5	2015	1.165
5	2022	1.162
7	2021	1.12
7	2018	1.12
9	2014	1.01
10	2010	0.99

Table 1. Rank of 10 warmest years in the instrumental record, based on GISS temperature analysis.

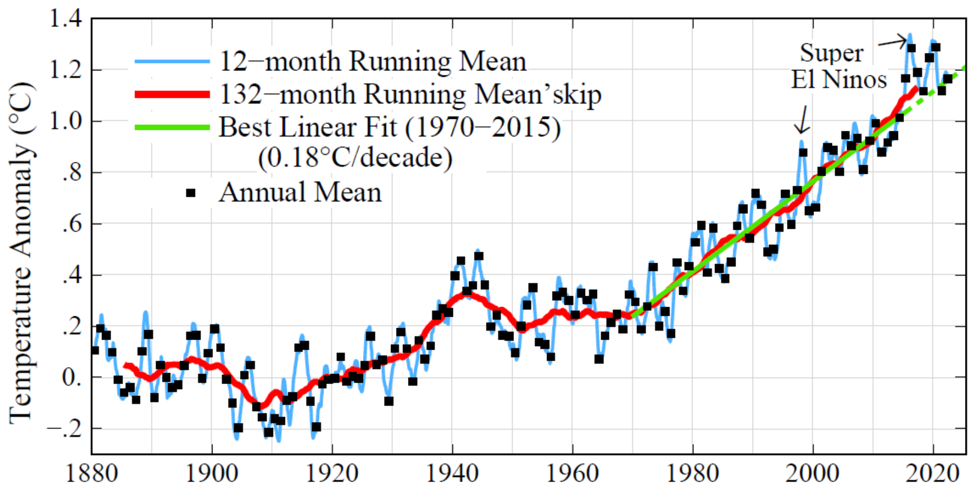

Fig. 2. Global surface temperature relative to 1880-1920 average.

The nine warmest years in the GISS record were the past nine years (Table 1). Global maps of temperature relative to 1880-1920 average are shown for these nine years chronologically in Fig. 1. La Nina cooling of the tropical Pacific Ocean was greatest in 2022 (lower right map in Fig. 1), yet global temperature rose moderately in 2022 (Fig. 2) rather than declining. We attribute global warming in the face of tropical cooling to the current unprecedented Earth Energy Imbalance (EEI, Fig. 3). The global temperature change is small, because in the past few years short-term tropical cooling has been opposing long-term human-made warming. That situation is poised to change rapidly during the next two years. There are two basic factors that will drive accelerated warming.

First, there is a large, persistent, planetary energy imbalance. EEI fluctuates from year-to-year because it is sensitive to cloud cover, which is sensitive to ocean dynamical variability. However, for the past decade Earth has been out of energy balance by more than 1 W/m^2 (Fig. 3), an increased imbalance traced to faster net growth rate of the human-made climate forcing. [4] During 1970-2010, greenhouse gas (GHG) forcing increased ~0.45 W/m^2 per decade, but this warming was partly offset by cooling from human-made aerosols, resulting in a net forcing increase of ~0.3 W/m^2 per decade. Since ~2010 aerosol climate forcing has been declining because of reduced air pollution in China and regulations on the sulfur content of fuels used by ships. Less aerosol cooling increases net forcing growth to 0.5-0.6 W/m^2, which should increase the decadal warming rate at least 50%.[4]

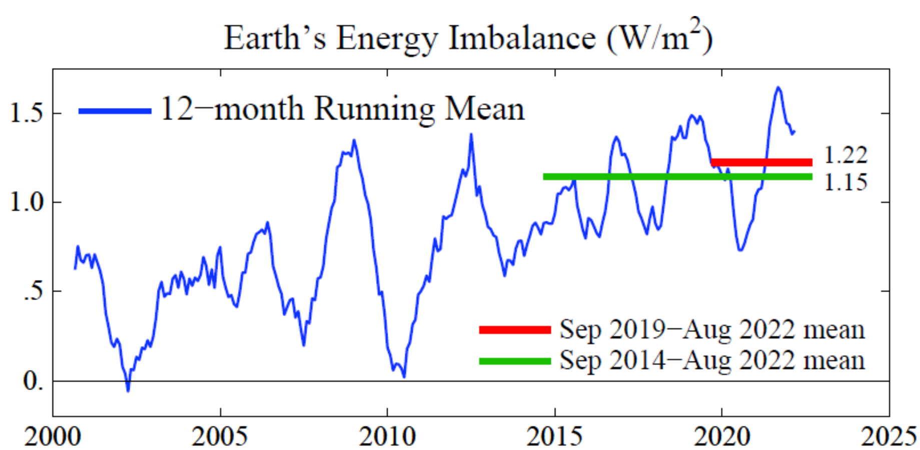

Fig. 3. 12-month running-mean of Earth's energy imbalance, based on CERES satellite data[5] for EEI change normalized to 0.71 W/m^2 mean for July 2005 – June 2015 from in situ data.

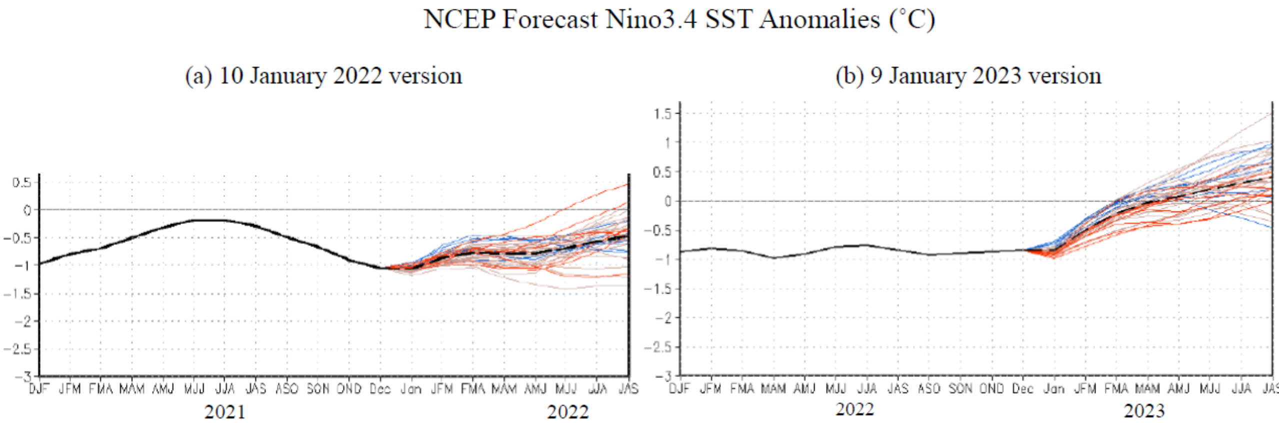

Fig. 4. NCEP forecasts[6] on Nino3.4 made in January 2022(a) and January 2023(b). La Nina is indicated by a value < –0.5C and El Nino by a value > +0.5°C.

Second, global climate models now consistently predict that the La Nina phase of tropical Pacific temperatures will draw rapidly to a close in 2023, with a shift to El Nino conditions in the second half of 2023. Fig. 4 shows results for the NOAA NCEP (National Center for Environmental Prediction) model. Last year the NCEP model predicted that the La Nina would continue (Fig. 4a); this prediction turned out to be correct. The NCEP model now predicts a return to neutral conditions (Nino3.4 between –0.5°C and +0.5°C) over the next few months, with an El Nino likely to begin in the latter half of the year. Other global models on average have a stronger trend toward El Nino.[6]

Although there is a consensus among the models that an El Nino is expected, the magnitude of the global warming is difficult to predict. The width of the "plume" of the forecasts by a single model (Fig. 4) indicates the forecast difficulty posed by inherent variability of the dynamical system. In contrast, the lag of global temperature change after warming in the tropics initiates is reasonably consistent for moderate and strong El Ninos. Global temperature, Nino3.4 temperature, and the

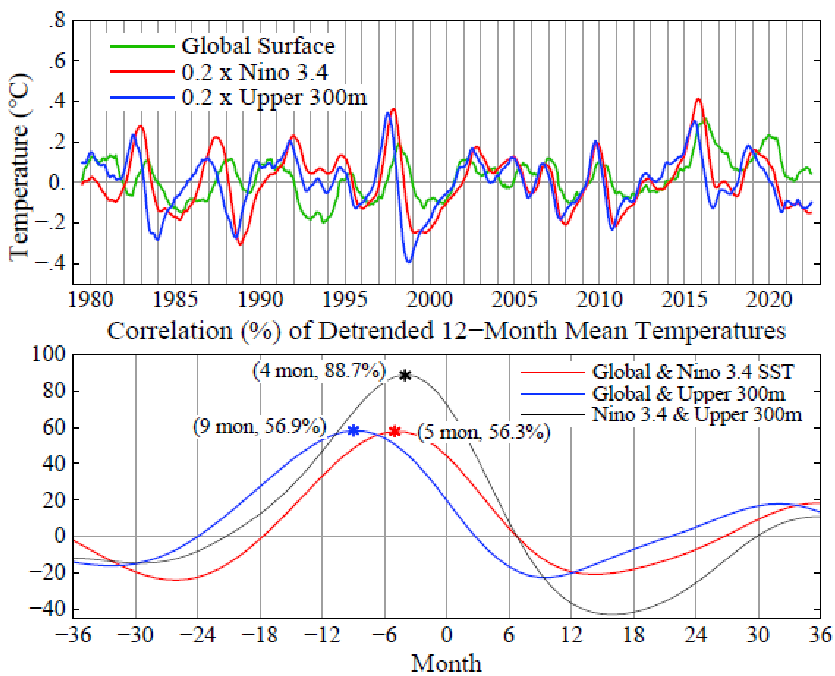

Fig. 5. Global, Nino3.4, and upper 300 m 12-month running-mean detrended temperature anomalies. Global temperature lags Nino3.4 by 5 months and 300 m temperature by 9 months.

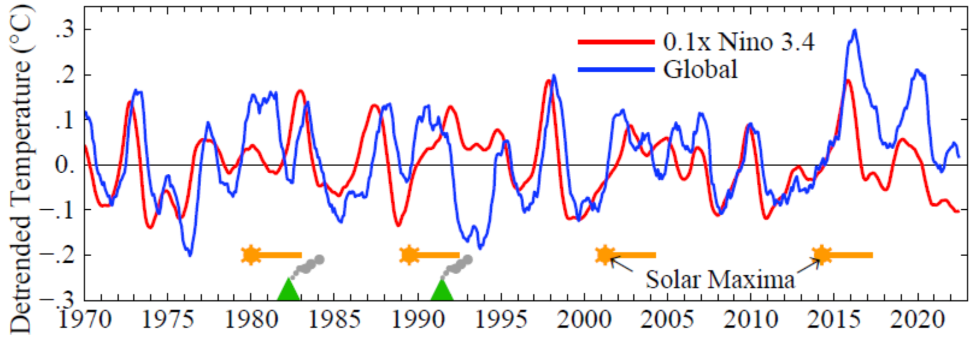

Fig. 6. 12-month running-mean temperatures detrended for 1970-2015.

temperature of the upper 300 m of the equatorial (longitude 100W-180W) ocean are compared in the upper part of Fig. 5 (for the period with data for all three). Nino3.4 and 300 m temperatures are highly correlated; the Nino3.4 temperature lags by the 4 months that it takes for the temperature anomaly to surface and reach the Nino3.4 area. Nino3.4 and 300 m temperatures are about equally good predictors of global temperature, both with correlations a bit less than 60 percent. The 300 m temperature provides a longer lead time for a prediction.

The consistent lag of global temperature after the Nino3.4 temperature for moderate and strong El Ninos is clearer in Fig. 6. We draw attention to the gap between global temperature during the past several years and the temperature "predicted" by Nino3.4. We suggest that the consistent difference between these two curves since 2015 is an indication of the effect on global temperature caused by the reduction of the human-made aerosol climate forcing. The difference between these two curves provides an approximate measure of this presumed aerosol effect. The large feature of the opposite sign in the early 1990s is due to the short-lived increase of stratospheric aerosols caused by the Pinatubo climate eruption.

The first payment of humanity's Faustian aerosol bargain[7] is now due. The first payment seems to be ~0.15°C. Like Dr. Faustus, who was hauled off screaming by Mephistopheles, we have no choice: we are going to make this payment, which together with the El Nino warming will likely take global temperature to +1.4-1.5°C in 2024 relative to 1880-1920. However, we still have options for dealing with this matter on the longer term, as we will discuss elsewhere.

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[1] Hansen, J., R. Ruedy, M. Sato, and K. Lo, 2010: Global surface temperature change. *Rev. Geophys.*, **48**, RG4004, doi:10.1029/2010RG000345.

[2] Lenssen, N.J.L., G.A. Schmidt, J.E. Hansen, M.J. Menne, A. Persin, R. Ruedy, and D. Zyss, 2019: Improvements in the GISTEMP uncertainty model, *J. Geophys. Res. Atmos.*, **124**, no. 12, 6307-6326, 10.1029/2018JD029522.

[3] The current GISS analysis employs NOAA ERSST.v5 for sea surface temperature, GHCN.v4 for meteorological stations, and Antarctic research station data, as described in references 1 and 2.

[4] Hansen, J., M. Sato, N. Loeb, L. Simons and K. von Schuckmann, Earth's energy imbalance and climate response time, 22 December 2022.

[5] Loeb, N. G., Johnson, G. C., Thorsen, T. J., Lyman, J. M., Rose, F. G., & Kato, S., Satellite and ocean data reveal marked increase in Earth's heating rate, *Geophys. Res. Lett.* **48**, e2021GL093047, 2021.

[6] NOAA National Center for Environmental Prediction forecasts are available and updated weekly. A new ensemble of climate model runs is made each week. Chart 24 in their Weekly ENSO Evolution, Status and Prediction shows the average of other global atmosphere-ocean models as "DYN AVG."

[7] Hansen, J., 2009: *Storms of My Grandchildren*, Bloomsbury, New York, 320 pages.